WDM REGENERATED TRANSMISSION SYSTEM

BACKGROUND OF THE INVENTION

Field of the invention

The present invention concerns wavelength-division multiplex fiber optic transmission systems and more particularly the regeneration of signals therein.

Description of the prior art

It is well known that to transmit optical signals over very long distances, as in the case of transoceanic transmission by submarine cable, it is necessary to amplify the optical signals periodically to compensate the attenuation of the signal and to reshape the signals to compensate distortion induced by the transmission medium or by interaction between the various signals of the multiplex. The distortion is compensated by “3R” regenerators ("3R" signifying "reshaping", "retiming" and "reamplifying") whose functions include reshaping the pulses, retiming the pulses and compensating pulse intensity losses in the regenerator.

Wavelength-division multiplexed (WDM) transmission systems are tending to include more and more channels (or wavelengths) on each optical fiber. The bit rate per channel is also increasing. Thus the most recent transoceanic transmission systems have a capacity of 32 channels each of 10 Gbit/s.

There are various ways to regenerate the signals of each channel in such systems. One solution is to demultiplex the signals and to regenerate each signal individually. However, this solution has the disadvantage of requiring as many regenerators as there are multiplexed signals which, given the trend for the number of channels to increase, leads to a complex and physically large regenerator, also requiring a powerful electrical power supply, which represent heavy penalties in the case of transmission via submarine cable.

Another solution which can be used in the case of soliton WDM signals (or RZ signals converted into solitons at the regenerator input) consists in using a regenerator including means for compensating chromatic dispersion in order to resynchronize the various channels followed by a synchronous modulator. This solution has the disadvantage of requiring very accurate control of chromatic dispersion so that the signals are perfectly synchronized at the input of the synchronous modulator. Controlling the chromatic dispersion is all the more difficult in that it must be achieved for a large number of channels.

It has also been proposed, in the case of WDM soliton signals, to dispose the regenerators along the optical line at locations where a certain number of

channels are naturally synchronous, and to regenerate only these channels at each of these locations (see WO-A-98 35459). However, this technique introduces a constraint on the position of the regenerators which can sometimes be problematical, depending on the number of channels and their wavelength spacing.

The invention proposes a simple solution to the problem of regenerating channels in a WDM transmission system, and one which remains simple even if the number of channels is high.

SUMMARY OF THE INVENTION

To be more precise, the invention proposes a multichannel wavelength-division multiplex fiber optic transmission system including an optical transmitter and an optical receiver connected by an optical line including at least one optical fiber and at least one set of channel regenerators, wherein successive regenerators regenerate respective groups of channels forming a subset of the set of channels.

The number of groups is preferably a submultiple of the total number of regenerators.

The groups of channels preferably include a small number of channels, in particular a single channel or two channels.

This greatly simplifies the structure of the regenerator, compared to the solutions which demultiplex all the signals or compensate chromatic dispersion of all the signals with respect to each other.

Each regenerator advantageously includes an optical regenerator unit.

If a plurality of channels are regenerated in the same regenerator, each regenerator can include means for synchronizing the channels to be regenerated and an optical regenerator unit, in particular a synchronous modulator.

In a first preferred embodiment of the invention each regenerator includes a demultiplexer and a multiplexer in order to process independently channels which are to be regenerated and channels which are not to be regenerated.

In a second preferred embodiment of the invention each regenerator includes an inserter/extractor system for isolating the channels which are to be regenerated.

A system in accordance with the invention can additionally include a compensator amplifier for compensating intensity differences between regenerated channels and non-regenerated channels.

The transmission system advantageously includes supervisory means using a dedicated channel. In a transmission system of the above kind, each

regenerator can include means for separating the dedicated channel from the other channels, a supervisory unit for modifying the signal of the dedicated channel as a function of information relating to the status of the regenerator, and means for remultiplexing the dedicated channel with the other channels.

In particular, each regenerator can include a regenerator unit for regenerating the channels of a group of channels, the supervisory unit receiving information from said regenerator unit and also receiving a fraction of the regenerated signal delivered by said regenerator unit.

The system of the invention preferably includes a plurality of spaced optical amplifiers and spaced optical regenerators and the spacing of the optical regenerators is preferably a multiple of the spacing of the optical amplifiers.

The features and advantages of the invention will emerge more clearly from the following description which is given with reference to the accompanying drawings and by way of illustrative and non-limiting example only.

BRIEF DESCRIPTION OF THE DRAWINGS

Sub B2 Figure 1 shows the ~~general structure of a prior art optical transmission system including~~ regenerators.

Figure 2 shows one embodiment of a regenerator in accordance with the invention.

Figure 3 shows a variant of the regenerator shown in figure 2 which is adapted to regenerate two channels.

Figure 4 shows another embodiment of a regenerator in accordance with the invention which is adapted to regenerate a single channel.

Figure 5 shows a variant of the regenerator shown in figure 4 which is adapted to regenerate two channels.

Figure 6 shows an optical transmission system in accordance with the invention equipped with optical supervisory means.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Sub a3 Figure 1 shows a conventional optical transmission system. It includes ~~two~~ terminal stations, namely a transmitter 2 and a receiver 4, connected by a fiber optic link 6. Amplifiers 8 are provided at regular intervals along the optical fiber to re-amplify the signals and so compensate losses due to absorption by the optical fiber. The distance Z_a between two successive amplifiers depends on many parameters (signal intensity, absorption by the optical fiber, wavelength separation between the signals, etc.); it is typically from 50 km to 100 km. The transmission system further

includes optical regenerators 10. The distance Z_r between two successive regenerators also depends on many parameters (Kerr effect, Gordon-Haus jitter, four-wave interaction, etc.) which affect the shape of the pulses and induce an offset of the pulses relative to their nominal bit time. The regenerators are generally disposed at a distance Z_a relative to an amplifier 10 and include an amplifier similar to the amplifiers 8. The distance Z_r between two regenerators is equal to $k.Z_a$, where k is an integer generally from 5 to 10 and depending in particular on the bit rate of the signals of the multiplex.

The invention differs from prior art transmission systems in that each regenerator regenerates a small number of channels. For example, for a WDM system with n wavelengths λ_1, λ_2, .., λ_n (n being equal to 32, for example), each regenerator could be designed to regenerate only one wavelength. In other words, the n channels could be divided into n groups G_1, G_2, ..., G_n each including only one channel. There would then be in succession along the line, with intervals Z_r between each regenerator and the next, a regenerator R_1 to regenerate the channel λ_1, a regenerator R_2 for the channel λ_2, ..., a regenerator R_n for the channel λ_n, another regenerator R_1 for the channel λ_1, etc. The important advantage is the simplification of the system by virtue of the fact that each regenerator has a simple structure.

Instead of a single channel per group, a transmission system can be provided in which the n channels are divided into n/2 groups, each including two channels, and more generally a system in which the n channels are divided into p groups each including n/p channels.

Finally, the channels can be divided unequally between the groups, for example two channels in group G_1, three channels in group G_2, two channels in group G_3, etc.

The description with reference to the subsequent figures shows that each regenerator has exactly the same structure. This simplifies the design of the system and the manufacture of the regenerators, which increases the reliability of the transmission system.

For example, for a transoceanic link of 32 channels at 10 Gbit/s and having a length in the order of 10 000 km, the distance Z_a between amplifiers is in the order of 40 km and the distance Z_r between regenerators is in the order of 320 km.

Sub a4 Figure 2 shows a first embodiment of a regenerator designed to regenerate only one channel. It has at the input a duplexer 12 for separating the channel λ_k to

be regenerated from the other channels λ_i ($1 \le i \le n$; $i \ne k$) and at the output a duplexer 14 for remultiplexing the channel λ_k with the other channels. The regenerator unit 16 can be of any type known in the art and advantageously includes a synchronous optical modulator in the case of soliton signals or RZ signals converted into solitons.

Generally, although optical regenerator units are currently preferred, the use of opto-electrical regenerator units, i.e. regenerator units in which the optical signals are converted into electrical signals, regenerated in electrical form and then converted back into optical signals, is not excluded from the scope of the present invention.

The regenerator units are powered by an electrical cable 18 (not shown in figure 1). A compensator amplifier 20 in the branch of the regenerator receiving the non-regenerated channels compensates the intensity difference between the non-regenerated channels and the channel λ_k. In some embodiments, there could instead be a compensator amplifier of this kind in the branch receiving the regenerator unit 16, should the latter induce an intensity loss in the channel λ_k.

When the regenerator 10 is at a distance Z_a from the preceding amplifier 8 (see figure 1), the regenerator 10 shown in figure 2 further includes an amplifier 8. This amplifier is preferably at the output of the regenerator 10, but could also be at its input. It could also replace the amplifier 20 shown in figure 2, in respect of the non-regenerated channels. In this case, the regenerator unit 16 would have also to include an amplifier at the output of the regenerator 10 to amplify the signals to be regenerated to the same intensity as non-regenerated signals. The latter arrangement is particularly beneficial because the number of signals that each amplifier must amplify is then smaller, as compared to the line amplifiers 8 (figure 1). Amplifiers of lower power or a greater power margin can then be used in the regenerators.

Figure 3 shows an embodiment similar to that shown in figure 2, but adapted to regenerate two channels λ_k and λ_{k+1}. The only difference compared to the regenerator shown in figure 2 is the provision of synchronization means 22 upstream of the regenerator unit 16 to synchronize the two channels to be regenerated. Synchronization means of this kind can simply be obtained, as shown here, with the aid of a three-port optical circulator 24 and a delay line 26 including two optical reflectors, for example Bragg filters 28, 30, spaced from each other so that the channels are resynchronized when they reach the regenerator unit 16. The

delay between the channels can be adjusted by means of a variable delay line 32.

Sub B3 Figure 4 shows a second embodiment of a regenerator designed to regenerate a single channel. It essentially includes an inserter/extractor system 33 which is a standard component in the field of optical transmission systems and a regenerator unit 16. The inserter/extractor system 33 includes a first three-port optical circulator 34, a section 36 of optical line provided with an optical reflector 38, for example a Bragg filter, to reflect the channel λ_k, and a second optical circulator 40. These components are arranged, in a manner well known in the art, to extract the channel λ_k from the optical line and to direct it to the input of the regenerator unit 16 and to insert the regenerated channel λ_k received from the regenerator unit 16 into the optical line.

It is important to note that the optical regenerator unit can be exactly the same for all the channels, for example in the case where the regenerator includes a synchronous modulator, with the result that the regenerator 10 can be adapted to any channel simply by choosing the wavelength to be reflected by the optical reflector 38. Thus the transmission system shown in figure 1 can be equipped with identical regenerators, which are "personalized" only in terms of the wavelength of the optical reflector 38, which simplifies manufacture, reduces costs and increases reliability.

The regenerator shown in figure 4 can be adapted, as shown in figure 5, to regenerate two channels λ_k and λ_{k+1}. This regenerator differs from that shown in figure 4 in that the line section 36 between the optical circulators 34 and 40 includes two optical reflectors for each channel. To be more precise, there are in succession on this line section: an optical reflector 42 for the channel λ_k, a variable delay line 44 and an optical reflector 46 for the channel λ_{k+1}, this combination forming resynchronization means similar to the resynchronization means 22 shown in figure 3, an optical reflector 48 for the channel λ_k and an optical reflector 50 for the channel λ_{k+1}.

The regenerator shown in figure 5 can be modified to regenerate more than two channels. Obviously, for this it is sufficient to add to the line section 36 optical reflectors adapted to reflect the channels to be regenerated and delay lines like the lines 44, if necessary.

Note that the compensator amplifier 20 of the regenerator shown in figure 2, intended to compensate an intensity difference between the channel or channels regenerated and non-regenerated channels, can be between the optical reflectors

46 and 48 in the case of the regenerator as shown in figure 5.

Over and above the structural simplicity of the transmission system in accordance with the invention, an additional advantage is the possibility of implementing a system element supervisory function in a simple manner. As is well known in the art, supervision consists in transmitting a signal over the line which is processed in each amplifier or regenerator to include therein information relating to the status, performance, etc. of the amplifiers and regenerators. This supervisory signal is on a specific channel in the bandwidth of the multiplex. The drawback of the prior art systems is that all the channels are regenerated simultaneously, which implies complex supervisory means in each regenerator (supervision of all WDM channels and associated synchronous modulators).

The transmission system in accordance with the invention has the advantage of enabling each regenerator to be supervised in a simpler manner.

Figure 6 shows a regenerator similar to that shown in figure 4, but with added supervisory means. The components identical to those in figure 4 carry the same reference numbers.

Sub B4 The supervisory means in the regenerator shown in figure 6 include: an optical reflector 52 for extracting and then inserting the supervisory channel λ_S, an optical coupler or demultiplexer 54 for separating the channels λ_K and λ_S extracted from the line by the circulator 34 and the reflectors 38, 52, an optical coupler or multiplexer 56 for remultiplexing the channels λ_K and λ_S after they have been processed, and a supervisory unit 58 for receiving information on the status of the regenerator 16 and on the status of the channel λ_K via an optical coupler 60 sampling a portion of the signal on the channel λ_K at the output of the regenerator unit 16, the supervisory unit 58 transmitting that information on the channel λ_S to the optical coupler or multiplexer 56.

Supervision is simpler than in the prior art because it takes account of only a small number of channels of the multiplex at each regenerator (only one channel in the case of figure 4).

The invention is not limited to the embodiments described but to the contrary encompasses all variants that are within the scope of the following claims.